On-line Simulation-based Network Control

Edwin K. P. Chong

and

Robert Givan

Electrical and Computer Engineering

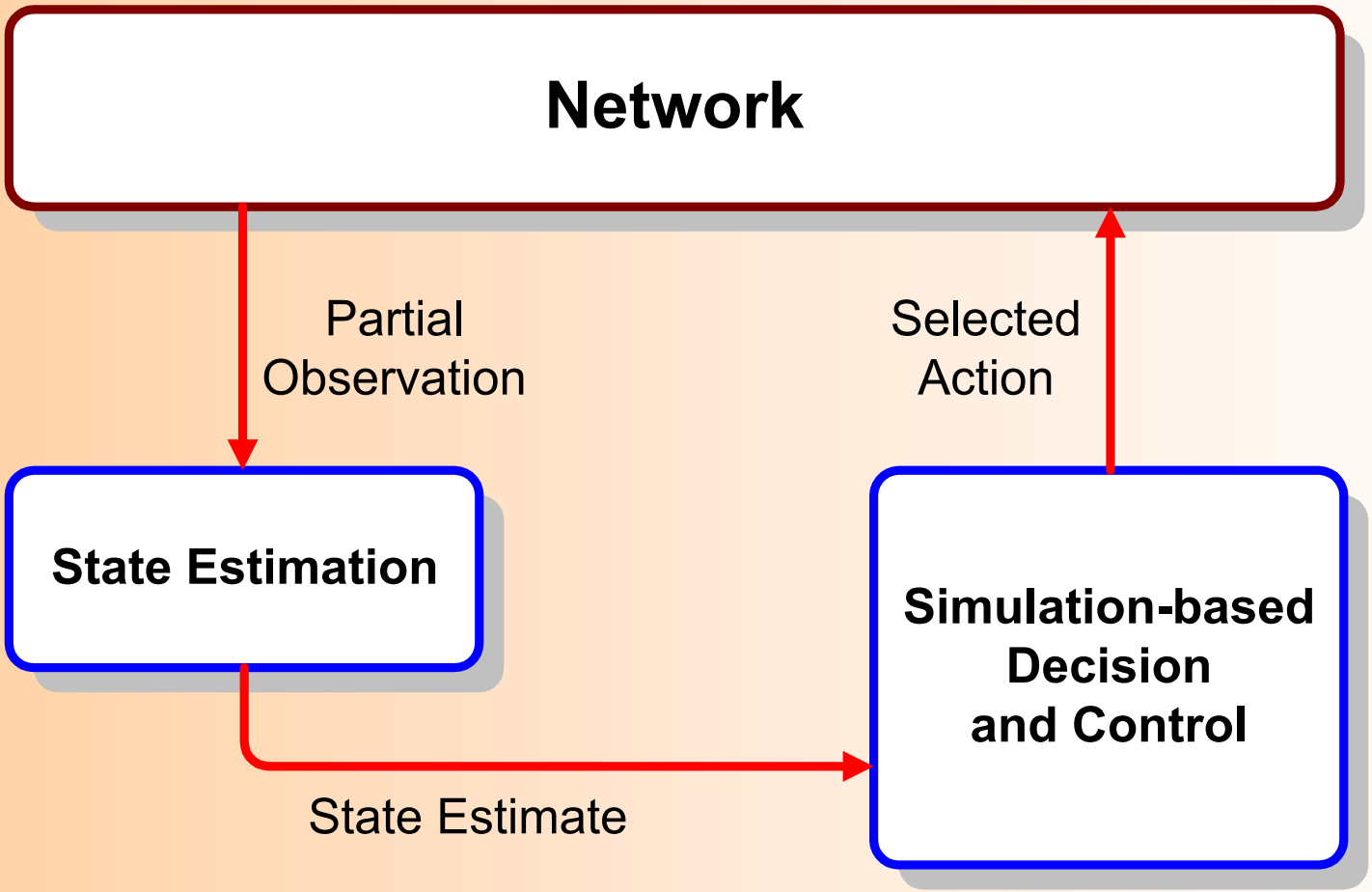
Purdue University

Research Overview

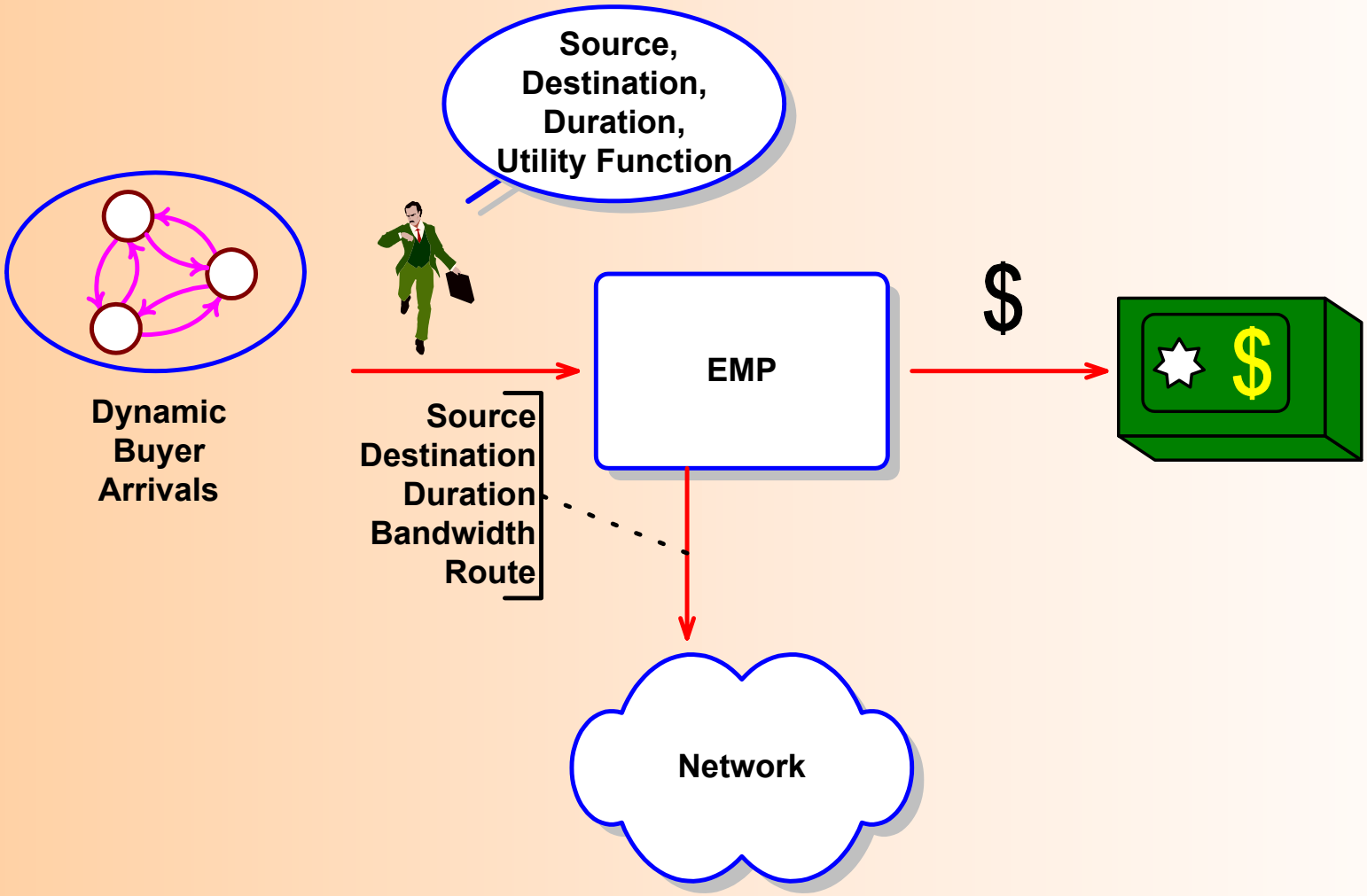
- **Simulation-based network control framework**
  - Enabling the use of network models for better control performance
- **Techniques under investigation**
  - Hindsight optimization
  - Parallel policy rollout
  - Neuro-dynamic programming
- **Applications at various network granularities**
  - Call level — admission control / bandwidth pricing / proxy management
  - Burst level — congestion control
  - Packet level — buffer management
- **Traffic modeling**
  - Multi-time-scale Markovian models

Edwin K. P. Chong
Robert Givan
Electrical and Computer Engineering
Purdue University

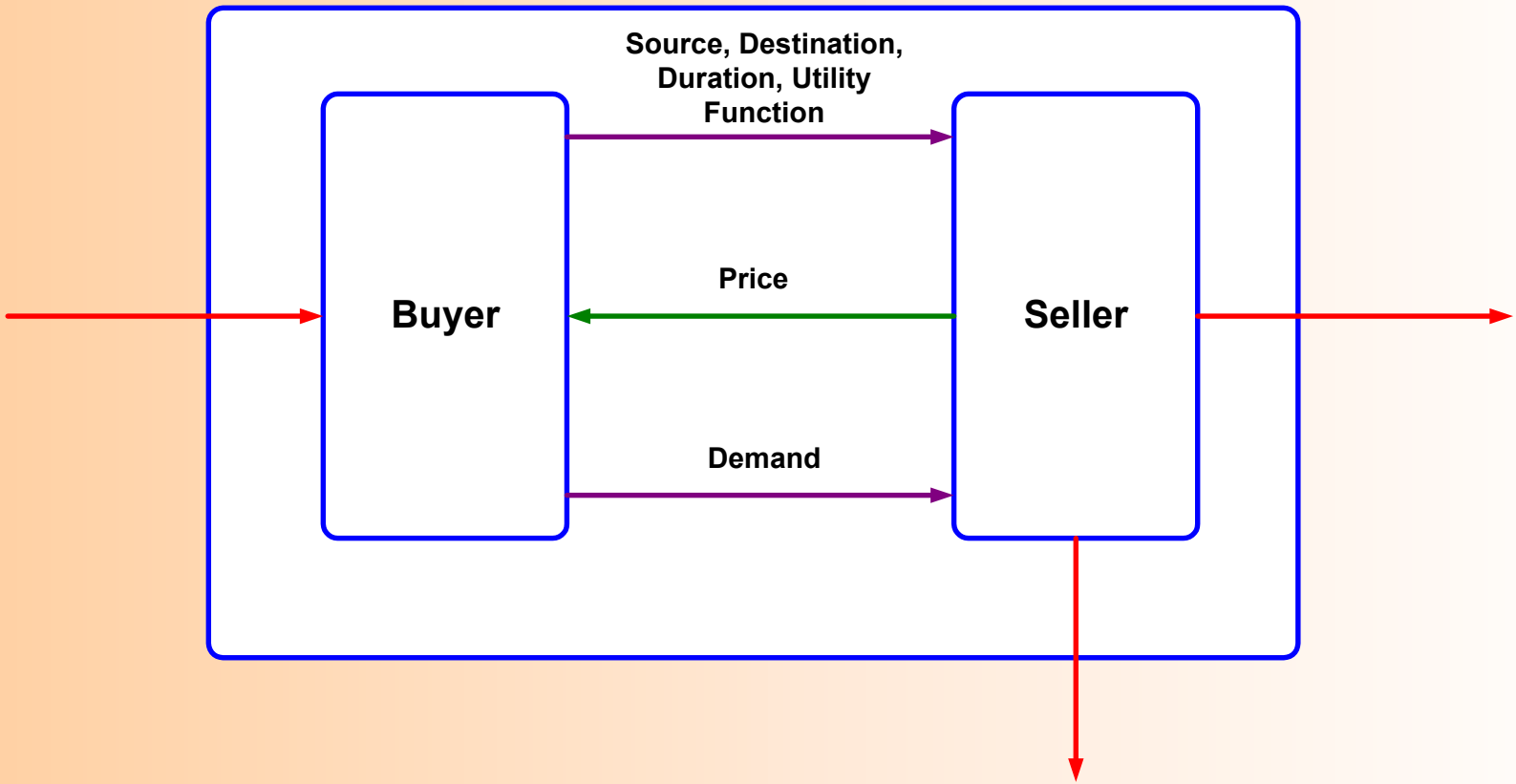
Control Architecture



Bandwidth Pricing



EMP Transaction



Optimal BW Pricing – Overview

- **Objective**
  - To find optimal prices to maximize the total revenue
  - To explore the use of seller's model of future demand
- **Traffic modeling**
  - Buyer arrival: Markov-modulated Poisson processes
  - Duration: Markov-modulated
- **Solution methods**
  - On-line traffic-state-based (reactive) pricing
  - Policy rollout
  - Adaptive policy rollout

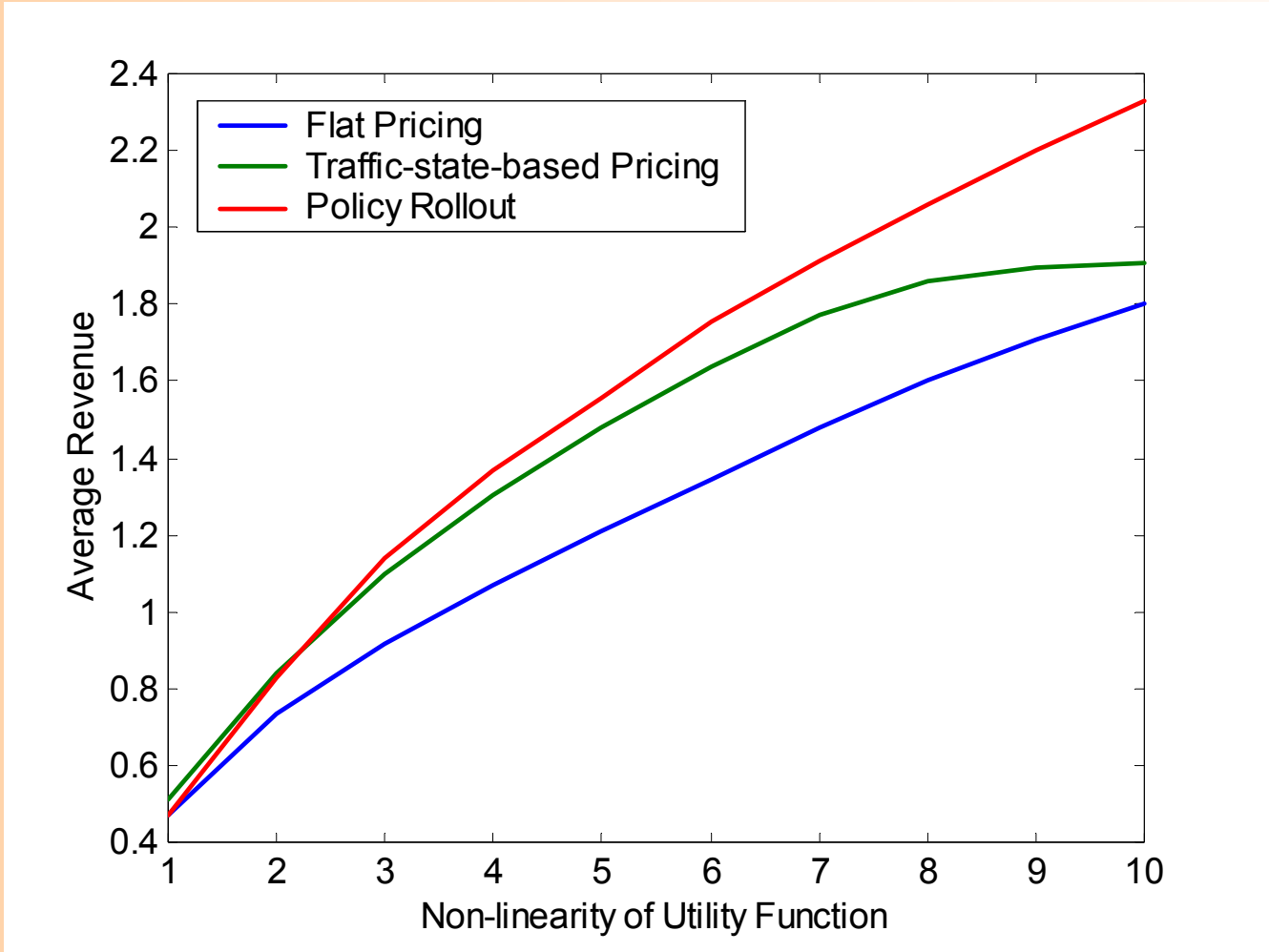
Optimal BW Pricing – Challenges

- **Arriving traffic could be bursty**
  - Should use this burstiness to our advantage
- **Price should react to the load variations**
  - Requires detection/prediction of variations
  - Update belief state based on arrivals
- **Load variations might occur at various timescales**

Optimal BW Pricing – Solutions

- **Traffic-state-based pricing**
  - Maintain belief state to capture traffic expectation
  - Tune prices as we observe traffic over time
- **Markov decision process modeling**
  - Policy rollout – rollout the traffic-state-based pricing policy
  - Adaptive policy rollout – rollout a state-based pricing policy and tune the various prices on-line using IPA
  - Hindsight optimization – use a gradient-based hindsight optimization technique
- **Adaptive policy rollout is a novel general control methodology**

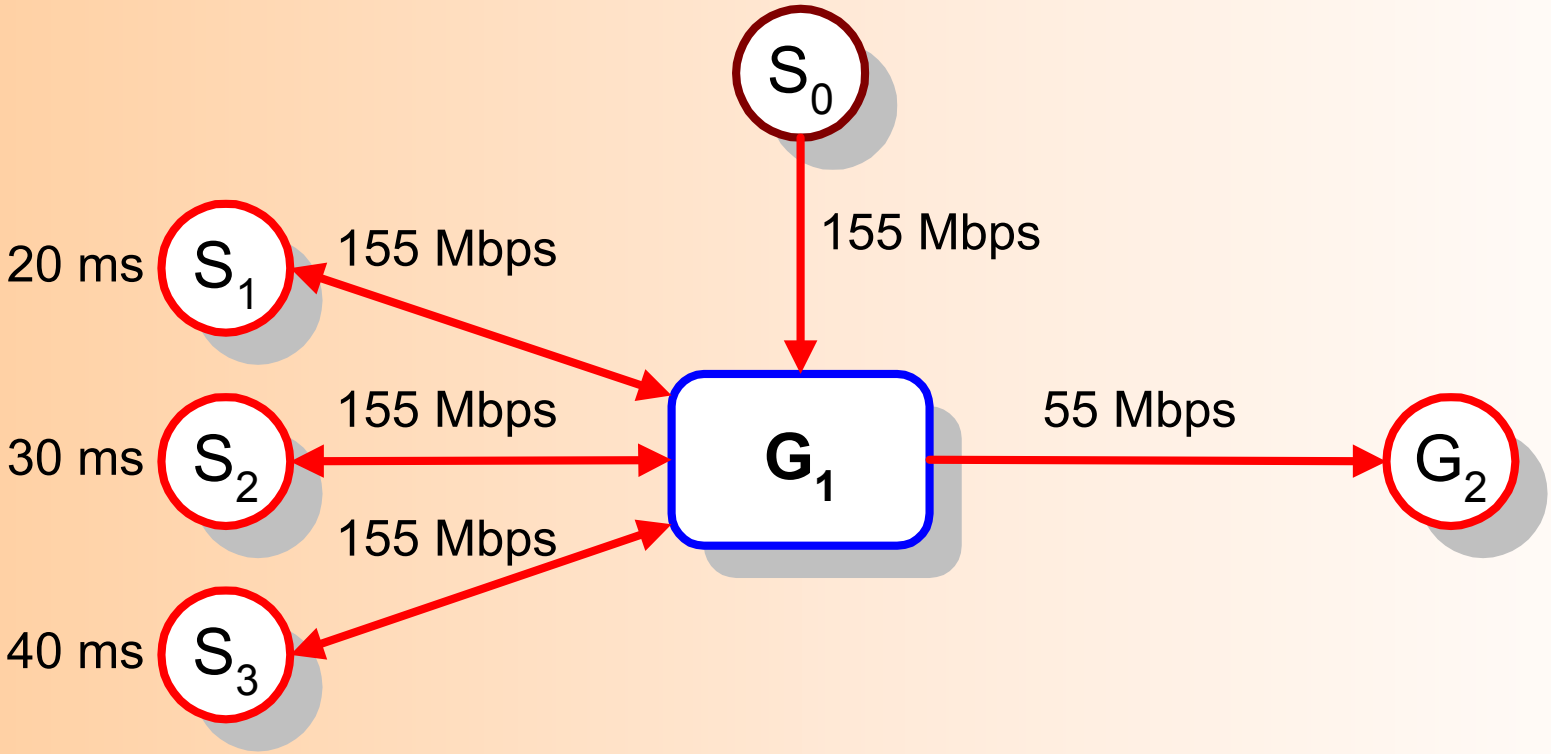
Optimal BW Pricing – Results



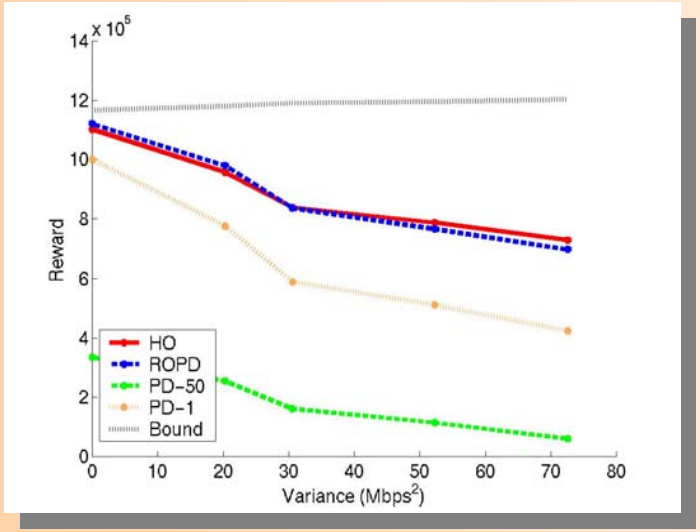
Congestion Control

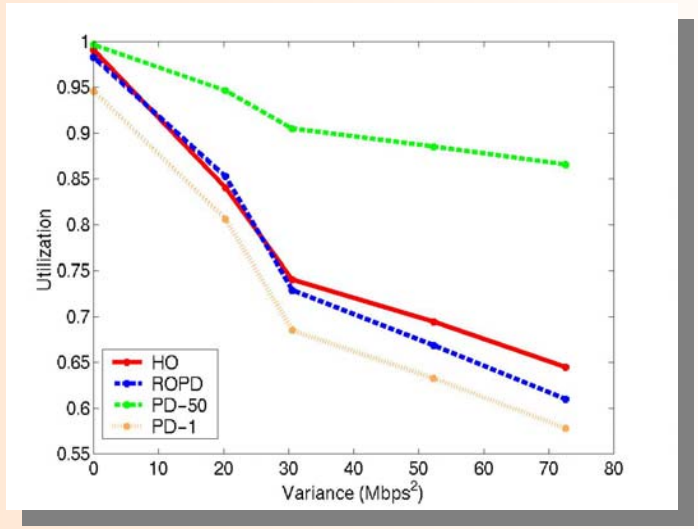
- **Objective: Use cross-traffic modeling to achieve**
  - High utilization
  - Low queuing delay
  - Low traffic loss
  - Fair service
- **Solution methods**
  - Markov-decision-process formulation
  - Stochastic fluid traffic model
  - Hindsight optimization (HO) and rollout (RO) algorithms
- **Results**
  - Higher network efficiency (represented by a combination of utilization, delay, and packet loss rate)
  - Fair service

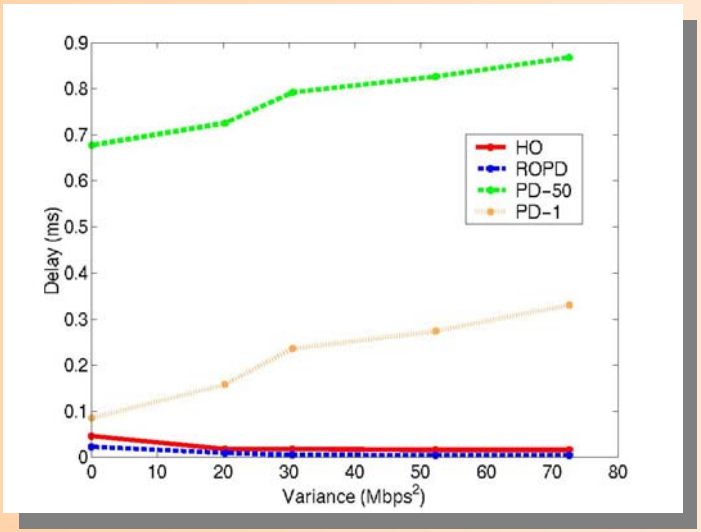
Evaluation Setup

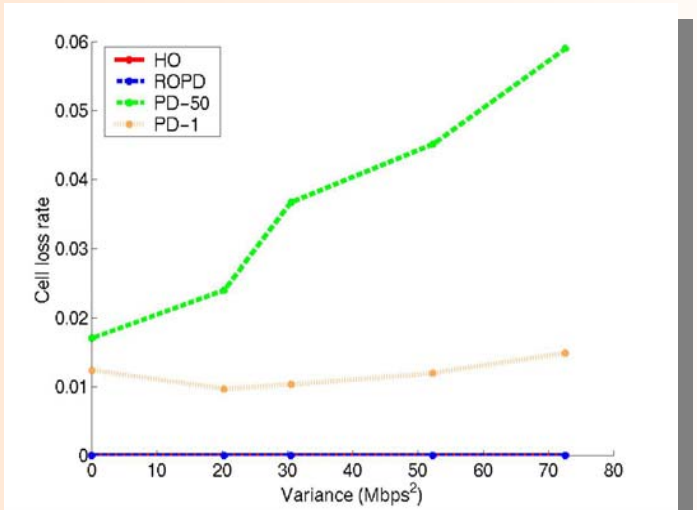


Empirical Results









Edwin K. P. Chong
Robert Givan
Electrical and Computer Engineering
Purdue University

Ongoing Work

- **Current status**
  - Modeling cross-traffic variation benefits control performance significantly.
  - Two approaches, HO and ROPD, achieve similar results, suggesting that the result is (close to) optimal.
- **Ongoing Work**
  - Extension to end-to-end scheme

Hierarchical Hidden Markov Models

- **An extension of Hidden Markov Models**
- **Capable of compactly capturing multiple timescales**
  - Capturing long-range correlations
  - State-based model
- **Properties of HHMM**
  - Each state of a HHMM also a HHMM
  - Generates sequences instead of symbols in each state by visiting sub-states in the lower level
  - Tree-like structure
- **Training of HHMM**
  - Generalized forward-backward algorithm
  - Generalized Viterbi algorithm

HHMM Structure

- **Types of states**
  - Internal states: have vertical and horizontal transitions; do not emit observable symbols
  - Production states: emit observable symbols according to a probability distribution over the set of output symbols
  - Terminal states: return control to the parent state
- **A simple HHMM**